Remarks

Claims 12-25 are pending in the application and subject to rejection. Reconsideration is requested in view of the following remarks.

Response to Section 103 Rejection of Claims 12-14,
16, 22 and 24-25 over Cassano in view of Erickson

Claims 12-14, 16, 22 and 24-25 have been rejected as allegedly unpatentable under 35 U.S.C. 103 over Cassano (US 4526775), as evidenced by Erickson (US 4132766). The rejection alleges that Cassano teaches the use of a molten alkali metal salt, preferably an alkali metal nitrite or nitrate, for separating oxygen from air. The rejection alleges that Erickson mentions that oxygen can be used in the manufacture of steel and in future coal conversion, and it would have been obvious to use concentrated, pressurized oxygen produced by Cassano as a reaction partner for combustion or oxidation reactions according to Erickson.

Neither Cassano nor Erickson teach the use of an ionic liquid, as that term is defined in the specification at page 4, lines 8-13, of the present application:

> "Ionic liquids" used as media according to the invention have been known *per se* for quite a while and are mainly used as solvents in organic and inorganic syntheses. *In contrast to classical molten salts, ionic liquids are already liquid at relatively low temperatures (< 80 °C) and have at the same time relatively low viscosities, i.e. good flowability. Furthermore, in contrast to many classical molten salts, they are not necessarily corrosive.* (emphasis added)

Even the free online encyclopedia *Wikipedia* (www.wikipedia.com) defines "ionic liquid" as including mentions the following :

> The term "ionic liquid" includes all classical molten salts, which are composed of more thermally stable ions, such as sodium with chloride or potassium with nitrate; the term dates back as early as 1943. [footnote omitted] Recently, it has come to be used for salts whose melting point is below an arbitrary set point of 100 °C.   (http://en.wikipedia.org/wiki/Ionic_liquid, accessed August 26, 2009, Appendix A)

The lowest melting alkali metal nitrate, lithium nitrate, does not melt below 261°C. *See,* John A Dean, *Lange's Handbook of Chemistry*, 14th ed., McGraw-Hill, Inc. 14th edition, 1992, p. 3.38 (Appendix B). Lithium is a very expensive metal. Accordingly, one would be inclined to use sodium or potassium salts in the practice of Cassano's and Erickson's inventions. The nitrites and nitrates of sodium and potassium have the following melting points: sodium nitrite, 271°C;

sodium nitrate 308°C; potassium nitrite, 441°C; and potassium nitrate, 334°C. *Lange's Handbook of Chemistry*, p. 3.46, 3.54 (Appendix B). Thus, none of the alkali metal salts of the asserted references would be considered an "ionic liquid".

As a consequence, both Cassano's and Erickson's teachings concern prior art methods similar to EP 306,840 A2, discussed in the present specification at page 3, lines 3-9. EP 306,840 A2, which document also discloses a method for separating oxygen from a gaseous mixture using alkali metal salts (i.e. nitrates, nitrites, oxides, peroxides, and superoxides). Apart from the high melting points of the salts used, which entail high energy costs in their utilization, the separation of oxygen from air according to Cassano, Erickson and EP 306,840 A2, can only be realized by chemisorption, *i.e.* chemical redox reactions of oxygen with nitrites, and not by solvatation or physisorption processes as additionally offered by the present invention, which is not limited to a particular way of binding the oxygen to the ionic liquid.

Thus, neither Cassano nor Erickson teach or suggest the use of an "ionic liquid" according to its currently understood definition (m.p. < 100 °C), particularly not according to the definition given in the present specification (m.p. < 80 °C). Consequently, the method recited by claim 12 would not have been obvious to one of ordinary skill in the art in view of the combined teachings of Cassano and Erickson.

Claims 13, 14, 16, 22 and 24-25 depend directly or indirectly from claim 12, and recite additional features of the method of claimed 12. In view of the allowability of claim 12, claims 14, 16, 22 and 24-25 are similarly allowable.

Response to Section 103 Rejection of Claims 12, 14,
15 and 17 over Ramprasad *et al.* in view of Erickson

Claims 12, 14, 15 and 17 have been rejected as allegedly unpatentable under 35 U.S.C. 103 over Ramprasad *et al.* (EP 583748A1), as evidenced by Erickson on the basis that Ramprasad *et al.* teaches the use of cobalt complexes for separating oxygen from air and Erickson mentions that oxygen can be used in the manufacture of steel and in future coal conversion.

As mentioned on page 5, line 4 of the Detailed Action, Ramprasad *et al.* describes the use of solutions of novel cobalt complexes for separating oxygen from gaseous mixtures, which

is again accomplished by chemisorption only, as in EP 306,840 A2, discussed above. What is more, the complexes according to Ramprasad *et al.* might even be infusible, *i.e.,* unmeltable, which is supported by the fact that Ramprasad *et al.* do not mention any melting points for the cobalt complexes that they first synthesize.

Thus, neither Ramprasad *et al.* nor Erickson teach or suggest the use of an "ionic liquid" according to its current definition (m.p. < 100 °C), particularly not according to the definition given in the present specification (m.p. < 80 °C). Consequently, the invention as recited in claim 12 is not rendered obvious by the combination of Ramprasad *et al.* and Erickson.

Claims 14, 15 and 17 depend directly or indirectly from claim 12, and recite additional features of the method of claimed 12. In view of the allowability of claim 12, claims 14, 15 and 17 are similarly allowable over the asserted combination of references.

Response to Section 103 Rejection of Claims 18-20 over
Cassano in view of Brennecke *et al.* and Sweeney *et al.*

Claims 18-20 have been rejected as allegedly unpatentable under 35 U.S.C. 103 over Cassano, in view of Brennecke *et al.* (US 6579343) and Sweeney *et al.* (US 5856533).

Claims 18-20 depend from claim 12, and recite additional features of the method of claimed 12. The deficiencies of Cassano, discussed above, are not remedied by Brennecke *et al.* or Sweeney *et al.* Accordingly, claim 18-20 are not rendered obvious by the combination of Cassano, Brennecke *et al.* and Sweeney *et al.*

Response to Section 103 Rejection of Claim 21 over
Cassano in view of Ramprasad *et al.* and Voorhees

Claim 21 has been rejected as allegedly unpatentable under 35 U.S.C. 103 over Cassano, in view of Ramprasad *et al.* and Voorhees (US 2196281).

Claim 21 depends from claim 12, and recites additional features of the method of claimed 12. The deficiencies of Cassano and Ramprasad *et al.,* discussed above, are not remedied by Voorhees. Accordingly, claim 21 is not rendered obvious by the combination of Cassano, Ramprasad *et al.* and Voorhees.

Response to Section 103 Rejection of Claim 23 over
Cassano in view of Ramprasad *et al.* and Horn *et al.*

Claim 23 has been rejected as allegedly unpatentable under 35 U.S.C. 103 over Cassano, in view of Ramprasad *et al.* and Horn *et al.* (US 6682794).
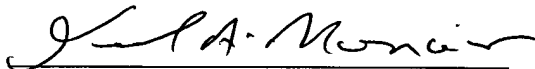
Claim 23 depends from claim 12, and recites additional features of the method of claimed 12. The deficiencies of Cassano and Ramprasad *et al.*, discussed above, are not remedied by Horn *et al.* Accordingly, claim 23 is not rendered obvious by the combination of Cassano, Ramprasad *et al.* and Horn *et al.*

Conclusion

The claims remaining in the application are believed to be in condition for allowance. An early action toward that end is earnestly solicited.

Respectfully submitted,

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APPENDIX A

Ionic liquid

From Wikipedia, the free encyclopedia

Ionic liquids, originally known as **liquid electrolytes, ionic melts, ionic fluids, fused salts, liquid salts,** or **ionic glasses,** is a term generally used to refer to salts that form stable liquids. Among other reasons, these liquid salts are of particular interest due to their extremely low- saturated vapor pressures.

From a lay perspective: an IL is a salt that forms a liquid at some temperature -- and which does not evaporate the way 'ordinary' liquids do. This characteristic has substantial scientific and commercial implications.


A 1-butyl-3-methylimidazolium (BMIM) salt.
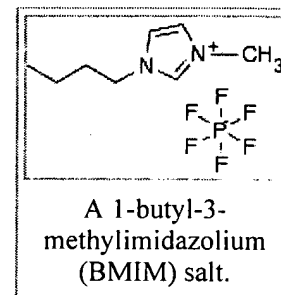
The entities comprising an IL are predominantly ions and ion-pairs. Ordinary table salt (sodium chloride) consists of sodium cations (Na+) and chloride anions (Cl−); when heated to several hundred degrees C, it melts (undergoes a phase change) into a liquid of mostly ions. While many combinations of bulkier and often more asymmetric organic ions also form well defined crystals, with well defined melting points, many instead form glasses prior to thermodynamically stable crystal lattice formation, where the crystallization kinetics are extremely slow. For example, the salt 1-ethyl-3-methylimidazolium dicyanamide, $[C_2mim]$

Ionic liquid model

$[N(CN)_2]$, melts at $T_m = -21$ °C[1], pyridinium chloride, [PyH]Cl, exhibits a melting point of $T_m = 144.5$ °C[2] but 1-butyl-3,5-dimethylpyridinium bromide, [N-butyl-3,5-dimethyl-Py]Br, exhibits glass formation at $T_g = -24$ °C.[3]
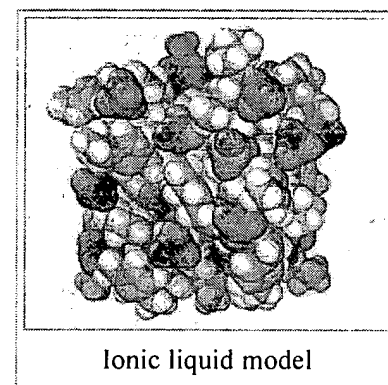
The term "ionic liquid" includes all classical molten salts, which are composed of more thermally stable ions, such as sodium with chloride or potassium with nitrate; the term dates back as early as 1943.[4] Recently, it has come to be used for salts whose melting point is below an arbitrary set point of 100 °C. There also exist mixtures of substances which have low melting points, called deep eutectic solvents, or DES, that have many similarities with ionic liquids.

Contents

History

The date of discovery of the "first" ionic liquid is disputed, along with the identity of the discoverer. Ethanolammonium nitrate (m.p. 52-55 °C) was reported in 1888 by Gabriel.[5] However, one of the earlier known truly room temperature ionic liquids was $[EtNH_3]^+$ $[NO_3]^-$ (m.p. 12 °C), the synthesis of which was published in 1914.[6] Much later, series of ionic liquids based on mixtures of 1,3-dialkylimidazolium or 1-alkylpyridinium halides and trihalogenoaluminates, initially developed for use as electrolytes, were to follow.[7][8] An important property of the imidazolium halogenoaluminate salts was that they were tuneable – viscosity, melting point and the acidity of the melt could be adjusted by changing the alkyl substituents and the ratio of imidazolium or pyridinium halide to halogenoaluminate. [9]

A major drawback was their moisture sensitivity and, though to a somewhat lesser extent, their acidity/basicity, the latter which can sometimes be used to an advantage. In 1992, Wilkes and Zawarotko reported the preparation of ionic liquids with alternative, 'neutral', weakly coordinating anions such as hexafluorophosphate ($[PF_6]^-$) and tetrafluoroborate ($[BF_4]^-$), allowing a much wider range of applications for ionic liquids.[10] It was not until recently that a class of new, air- and moisture stable, neutral ionic liquids, was available that the field attracted significant interest from the wider scientific community.

More recently, people have been moving away from $[PF_6]^-$ and $[BF_4]^-$ since they are toxic, and towards new anions such as bistriflimide $[(CF_3SO_2)_2N]^-$ or even away from halogenated compounds completely. Moves towards less toxic cations have also been growing, with compounds like ammonium salts (such as choline) being just as flexible a scaffold as imidazole.

Characteristics

Ionic liquids are often moderate to poor conductors of electricity, non-ionising (e.g. non-polar), highly viscous and frequently exhibit low a vapour pressure. Their other properties are diverse: many have low combustibility, excellent thermal stability, wide liquidus regions, and favourable solvating properties for a range of polar and non-polar compounds. Many classes of chemical reactions, such as Diels-Alder reactions and Friedel-Crafts reactions, can be performed using ionic liquids as solvents. Recent work has

shown that ionic liquids can serve as solvents for biocatalysis.[11] The miscibility of ionic liquids with water or organic solvents varies with sidechain lengths on the cation and with choice of anion. They can be functionalized to act as acids, bases or ligands, and have been used as precursor salts in the preparation of stable carbenes. Because of their distinctive properties, ionic liquids are attracting increasing attention in many fields, including organic chemistry, electrochemistry, catalysis, physical chemistry, and engineering; see for instance magnetic ionic liquid.

Despite their extremely low vapor pressures, some ionic liquids can be distilled under vacuum conditions at temperatures near 300 °C.[12] In the original work by Martyn Earle, et al., the authors wrongly assumed the vapour to be comprised of individual, separated ions,[13] but it was later proven that the vapours formed consisted of ion-pairs.[14] Some ionic liquids (such as 1-butyl-3-methylimidazolium nitrate) generate flammable gases on thermal decomposition. Thermal stability and melting point depend on the components of the liquid. Thermal stability of various RTILs are available. The thermal stability of a task-specific ionic liquid, protonated betaine bis(trifluoromethanesulfonyl) imide is of about 534 K and N-Butyl-N-Methyl pyrrolidinium bis(trifluoromethanesulfonyl)imide was thermally stable up to 640 K.[15]

The solubility of different species in imidazolium ionic liquids depends mainly on polarity and hydrogen bonding ability. Saturated aliphatic compounds are generally only sparingly soluble in ionic liquids, whereas olefins show somewhat greater solubility, and aldehydes can be completely miscible. This can be exploited in biphasic catalysis, such as hydrogenation and hydrocarbonylation processes, allowing for relatively easy separation of products and/or unreacted substrate(s). Gas solubility follows the same trend, with carbon dioxide gas showing exceptional solubility in many ionic liquids, carbon monoxide being less soluble in ionic liquids than in many popular organic solvents, and hydrogen being only slightly soluble (similar to the solubility in water) and may vary relatively little between the more commonly used ionic liquids. (Different analytical techniques have yielded somewhat different absolute solubility values.)

Room temperature ionic liquids

Room temperature ionic liquids consist of bulky and asymmetric organic cations such as 1-alkyl-3-methylimidazolium, 1-alkylpyridinium, N-methyl-N-alkylpyrrolidinium and ammonium ions. A wide range of anions are employed, from simple halides, which generally inflect high melting points, to inorganic anions such as tetrafluoroborate and hexafluorophosphate and to large organic anions like bistriflimide, triflate or tosylate. There are also many interesting examples of uses of ionic liquids with simple non-halogenated organic anions such as formate, alkylsulfate, alkylphosphate or glycolate. As an example, the melting point of 1-butyl-3-methylimidazolium tetrafluoroborate or **[bmim][BF$_4$]** with an imidazole skeleton is about -80 °C, and it is a colorless liquid with high viscosity at room temperature.

It has been pointed out that in many synthetic processes using transition metal catalyst, metal nanoparticles play an important role as the actual catalyst or as a catalyst reservoir. It also been shown that ionic liquids (ILs) are an appealing medium for the formation and stabilization of catalytically active transition metal nanoparticles. More importantly, ILs can be made that incorporate coordinating groups,[16] for example, with nitrile groups on either the cation or anion (CN-IL). In various C-C coupling reactions catalyzed by palladium catalyst, it has been found the palladium nanoparticles are better stabilized in CN-IL compared to non-functionalized ionic liquids; thus enhanced catalytic activity and recyclability are realized. [17]

Low temperature ionic liquids

Low temperature ionic liquids (below 130 kelvins) have been proposed as the fluid base for an extremely large diameter spinning liquid mirror telescope to be based on the Earth's moon.[18] Low temperature is advantageous in imaging long wave infrared light which is the form of light (extremely red-shifted) that arrives from the most distant parts of the visible universe. Such a liquid base would be covered by a thin metallic film that forms the reflective surface. A low volatility is important for use in the vacuum conditions present on the moon.

Food science

Ionic liquids have been used in food science. **[bmim]Cl** for instance is able to completely dissolve freeze dried banana pulp and the solution with an additional 15% DMSO lends itself to Carbon-13 NMR analysis. In this way the entire banana compositional makeup of starch, sucrose, glucose, and fructose can be monitored as a function of banana ripening.[19]

Applications

Nowadays ionic liquids find a number of industrial applications which vary greatly in character. A few of their industrial applications are briefly described below; more detailed information can be found in a recent review article.[20]

BASIL

The first major industrial application of ILs was the BASIL (*B*iphasic *A*cid *S*cavenging utilizing *I*onic *L*iquids) process by BASF, in which a 1-alkylimidazole was used to scavenge the acid from an existing process. This then results in the formation of an IL which can easily be removed from the reaction mixture.[21] But the easier removal of an unwanted side-product (as an IL rather than as a solid salt) is not the only advantage of the IL based process. By using an IL it was possible to increase the space/time yield of the reaction by a factor of 80,000. It should, however, be kept in mind that improvements of such scale are rare.

Cellulose Processing

Occurring at a volume of some 700 billion tons, cellulose is the earth's most widespread natural organic chemical and, thus, highly important as a bio-renewable resource. But even out of the 40 billion tons nature renews every year, only approx. 0.2 billion tons are used as feedstock for further processing. A more intensive exploitation of cellulose as a bio-renewable feedstock has to date been prevented by the lack of a suitable solvent that can be used in chemical processes. Robin Rogers and co-workers at the University of Alabama have found that by means of ionic liquids, real solutions of cellulose can now be produced for the first time at technically useful concentrations.[22] This technology therefore opens up great potential for cellulose processing. Although it has been presented as a new idea, the use of ionic liquids in cellulose processing originally dates back to 1934 in a patent by Graenacher where mixtures of 1-ethylpyridinium chloride with free nitrogen containing bases were used.[23]

For example, making cellulosic fibers from so-called dissolving pulp currently involves the use, and

subsequent disposal, of great volumes of various chemical auxiliaries, esp. carbon disulfide (CS_2). Major volumes of waste water are also produced for process reasons and need to be disposed of. These processes can be greatly simplified by the use of ionic liquids, which serve as solvents and are nearly entirely recycled. The "Institut für Textilchemie und Chemiefasern" (ITCF) in Denkendorf and BASF are jointly investigating the properties of fibers spun from an ionic liquid solution of cellulose in a pilot plant setup.[24] The dissolution of cellulose based materials like tissue paper waste, generated at chemical industries and at research laboratories, in room temperature ionic liquid, 1-butyl-3-methylimidazolium chloride, bmimCl, was studied and the recovery of valuable compounds by electrodeposition was studied from this cellulose matrix.[25]

Eastman chemical's DHF plant

Eastman operated an ionic liquid-based plant for the synthesis of 2,5-dihydrofuran from 1996 to 2004. However, the plant is now defunct because demand for the product has ceased.

Dimersol - Difasol

The dimersol process is a traditional way to dimerise short chain alkenes into branched alkenes of higher molecular weight. Nobel laureate Yves Chauvin and Hélène Olivier-Bourbigou at IFP (France) have developed an ionic liquid-based add-on to this process called the Difasol process. However, while may be licensed it has as yet not been put into commercial practice.

Petrochina

Petrochina have announced the implementation of an ionic liquid-based process called Ionikylation. This process, the alkylation of C4 olefins with iso-butane, is retrofitted into a 65,000 tonne per year alkylation plant, making it the biggest industrial application of ILs to date.

Evonik paint additives

Ionic liquids can enhance the finish, appearance and drying properties of paints. Evonik is marketing such ILs under the name of TEGO Dispers. These products are also added to the Pliolite paint range.

Air products - ILs as a transport medium for reactive gases

Air products make use of ILs as a medium to transport reactive gases in. Reactive gases such as trifluoroborane, phosphine or arsine, BF3, PH3 or AsH3, respectively, are stored in suitable ILs at sub-ambient pressure. This is a significant improvement over pressurised cylinders. The gases are easily withdrawn from the containers by applying a vacuum.

Linde's IL 'piston'

Whereas Air Product's Gasguard system relies on the solubility of some gases in ILs, Linde are exploiting other gases' insolubility in ILs. As mentioned above, the solubility of hydrogen in ILs is very low. Linde now make use of this insolubility by using a body of ionic liquid to compress hydrogen up to 450 bar[26] in filling stations; and in so doing they reduced the number of moving parts from about 500 in a conventional piston pump engine down to 8.

IOLITEC's dispersions of nano-materials

It is well known that ILs can be used for the synthesis of nano-scaled materials. IOLITEC has developed a couple of methods for the dispersion of different combinations of solvents and nano-materials, using the unusual physical properties of ionic liquids. The dispersion is useful, since it enables a safer use of nano-scaled materials in typical applications.

Nuclear industry

RTILs are extensively explored for various innovative applications in nuclear industry. It includes application of ionic liquid as extractant/diluent in solvent extraction systems, as alternate electrolyte media for the high temperature pyrochemical processing, etc. Fundamental studies on the extraction methods for electrodeposition of fission products like uranium, palladium etc., from spent nuclear fuel using RTILs as extractants are reported. Reports on employing using Ionic liquids as non-aqueous electrolyte media for the recovery of uranium,[27] lanthanides,[28] and useful fission products like palladium[29], rhodium[30] and even ruthenium [31] from spent nuclear fuel are also available. Ionic liquids have been explored as diluents for the liquid-liquid extraction of actinides. Recently a novel process using ionic liquids, namely, Extraction-Electrodeposition was developed and demonstrated for the recovery of palladium [32]. Studies on the electrochemical behavior of uranium(VI) in ionic liquid, 1-butyl-3-methylimidazolium chloride and also the recovery of valuable fission products from tissue paper waste was studied in room temperature ionic liquids.[33] The dissolution properties of uranium oxides, UO_3, UO_2, and U_3O_8 and their individual separation was studied using a task-specific ionic liquid, namely protonated betaine bis(trifluoromethanesulfonyl) imide, [Hbet][NTf$_2$].[34]

Solar Energy Applications

Ionic liquids show great potential for use as a heat transfer and storage medium in solar thermal energy systems. Concentrating solar thermal facilities such as parabolic troughs and solar power towers utilise the energy of the sun by focusing it onto a receiver which can generate temperatures of around 600C. This heat can then be used to generate electricity in a steam or other cycle. For buffering during cloudy periods or to enable generation overnight, some of this energy can be stored by heating an intermediate fluid. Although nitrate salts have been the medium of choice since the early 1980s, they freeze at 220C and thus require heat tracing overnight to prevent solidification. Ionic liquids such as [C$_4$mim][BF$_4$] have been identified with more favourable liquid-phase temperature ranges (-75C to 459C) and could therefore be excellent liquid thermal storage media and heat transfer fluids in solar thermal power plants. [35]

Hydrogen Storage

Ionic liquids have several properties that make them viable options for hydrogen storage systems. For instance, the vapor pressure of ionic liquids is very low and is negligible in most situations. These liquid are also stable at high temperatures. In addition, ionic liquids are able to act as solvents for a wide variety of compounds and gases, they also have weakly coordinating anions and cations which are able to stabilize polar transition states. Finally, the liquids are able to be reused with minimal loss of activity. In their research Karkamkar et al. used 1-butyl-3-methylimidazolium chloride (bmimCl) in the dehydrogenation of ammonia borane. Immediately upon heatings the sample, hydrogen evolution took

place with a final value of hydrogen evolution as high as 5.4 wt% H_2.[36]

Natural Product Extraction

Ionic liquids are proving superior to conventional solvents in the extraction of specific natural compounds from plant biomass for pharmaceutical, nutraceutical and cosmetic applications. For example, a series of protic ionic liquids have been evaluated as solvents for the isolation of the important antimalarial drug artemisinin from the plant *Artemisia annua*. Lapkin et al. conducting a benchmarking study taking in a consideration of operational parameters, in which the ionic liquid equalled or outperformed the alternatives.[37] Following subsequent process development studies, Bioniqs is currently commerciallizing a protic ionic liquid for artemisinin extraction.

Waste Recycling

Ionic liquids can be developed for the recycling of synthetic goods, plastics and metals. They offer the specificity required to separate similar compounds from each other, such as in the separation of polymers from plastic waste streams. This has achieved this using lower temperature extraction processes than current approaches[1]and could be the answer to avoiding tonnes of plastics being incinerated or consigned to landfill each year.

Gas Treating

As profiled in the July 13, 2009 issue of C&E News, ION Engineering is commercializing technology using ionic liquids and amines for CO_2 capture and natural gas sweetening.

Safety

Due to their non-volatility, effectively eliminating a major pathway for environmental release and contamination, ionic liquids have been considered as having a low impact on the environment and human health, and thus recognized as solvents for green chemistry. However, this is distinct from toxicity, and it remains to be seen how 'environmentally-friendly' ILs will be regarded once widely used by industry. Research into IL aquatic toxicity has shown them to be as toxic or more so than many current solvents already in use.[38] Review papers on this aspect have been published in 2007.[39][40] Available research also shows that mortality isn't necessarily the most important metric for measuring their impacts in aquatic environments, as sub-lethal concentrations have been shown to change organisms' life histories in meaningful ways. According to these researchers balancing between zero VOC emissions, and avoiding spills into waterways (via waste ponds/streams, etc.) should become a top priority. However, with the enormous diversity of substituents available to make useful ILs, it should be possible to design them with useful physical properties and less toxic chemical properties.

With regard to the safe disposal of ionic liquids, a 2007 paper has reported the use of ultrasound to degrade solutions of imidazolium-based ionic liquids with hydrogen peroxide and acetic acid to relatively innocuous compounds.[41]

Despite their low vapor pressure many ionic liquids have also found to be combustible and therefore require careful handling.[42] Brief exposure (5 to 7 seconds) to a flame torch will ignite these IL's and some of them are even completely consumed by combustion.

See also

- MDynaMix software for ionic liquids simulations[43]
- 1-Butyl-3-methylimidazolium hexafluorophosphate (BMIM-PF$_6$) for an often encountered ionic liquid.
- Aza-Baylis-Hillman reaction for the use of a chiral ionic liquid in asymmetric synthesis.
- Deep eutectic solvent
- Trojan wave packet

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APPENDIX B

LANGE'S
HANDBOOK
OF
CHEMISTRY

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Fourteenth Edition

TABLE 3.2 Physical Constants of Inorganic Compounds (*Continued*)

Name	Formula	Formula weight	Density	Melting point, °C	Boiling point, °C	Solubility (in 100 parts solvent)
Lithium						
nitrate	$LiNO_3$	68.94	2.38	261		50 g/100 mL[20] aq; s alc
nitride	Li_3N	34.82		813		d aq
oxide	Li_2O	29.88	2.013[25]	1570(?)	2563	forms LiOH in aq
perchlorate	$LiClO_4$	106.40	2.43[25]	236	d 400, LiCl	37.5 g/100 mL[25] aq; v s organic solv
peroxide	Li_2O_2	45.88		d >195 to Li_2O		d dil HCl
silicate(2−)	Li_2SiO_3	89.97	2.52[25]	1201(1)		34.5 g/100 mL[20] aq; i alc
sulfate	Li_2SO_4	109.95	2.22	859(1)		sl s aq
tetraborate(2−)	$Li_2B_4O_7$	169.12		917(2)		d aq, alc; g/100 mL: 30 eth, 13 THF; flammable
tetrahydridoaluminate	$LiAlH_4$	37.95	0.917	d 137(10)		s aq pH >7; s eth, THF
tetrahydridoborate	$LiBH_4$	21.79	0.666	268	d 380	s acids
Lutetium	Lu	174.967	9.84[25]	1652	3402	s acids
chloride	$LuCl_3$	281.33	3.98	892(2)	subl >750	s aq
sulfate 8-water	$Lu_2(SO_4)_3 \cdot 8H_2O$	782.25				42.3 g/100 mL[20] aq
Magnesium	Mg	24.305	1.738[20]	650	1110(10)	i aq; s dilute acids
acetate	$Mg(C_2H_3O_2)_2$	142.00	1.42	323 d		53.4 g/100 mL[20] aq; v s alc
aluminate(2−)	$MgAl_2O_4$	142.27	3.6	2135		v sl s HCl
amide	$Mg(NH_2)_2$	56.37	1.39[25]	ign in air		d viol water giving NH_3
borate(1−) 8-water	$Mg(BO_2)_2 \cdot 8H_2O$	254.06	2.30			sl s aq; s acids
bromide	$MgBr_2$	184.13	3.722	711(15)	1158	101 g/100 mL[20] aq
carbonate	$MgCO_3$	84.32	2.958	d 402		0.01 aq; s acids
chloride	$MgCl_2$	95.23	2.41	714	1437	54.6 g/100 mL[20] aq
fluoride	MgF_2	62.31	3.148	1248	2260	0.013[25] aq; s HNO_3
(*di-*) germanide	Mg_2Ge	121.21		1115		
hexafluorosilicate 6-water	$Mg[SiF_6] \cdot 6H_2O$	274.48	1.788	$-SiF_4$, 120		51 g/100 mL[20] aq; i alc
hydride	MgH_2	26.34	1.45	d 287 vacuo	ign in air	d aq and alc violently
hydrogen phosphate 3-water	$MgHPO_4 \cdot 3H_2O$	174.34	2.123[15]	anhyd 205		sl s aq; s acids
hydroxide	$Mg(OH)_2$	58.33	2.36	269.1 d	d 550	i aq; s acids
iodide	MgI_2	278.12	4.43	634(15)		140 g/100 mL[20] aq; s alc
lactate 3-water	$MgC_6H_{10}O_6 \cdot 3H_2O$	256.52				4 g/100 mL aq; sl s alc

TABLE 3.2 Physical Constants of Inorganic Compounds (*Continued*)

Name	Formula	Formula weight	Density	Melting point, °C	Boiling point, °C	Solubility (in 100 parts solvent)
Potassium						
hexafluorozirconate	$K_2[ZrF_6]$	283.41	3.58	d 200		2.7 g/100 mL[20] aq
hexanitritocobaltate(III) 1.5-water	$K_3[Co(NO_2)_6]\cdot1.5H_2O$	479.30				0.089[17] aq; s HOAc; v sl s alc
hydride	KH	40.11	1.43	417 d		d aq
hydrogen carbonate	$KHCO_3$	100.11	2.17	d > 100		34 g/100 mL[20] aq; i alc
hydrogen difluoride	KHF_2	78.11	2.37	238.80	d 477	39 g/100 mL[20] aq; s alc
hydrogen phosphate	K_2HPO_4	174.18		d to $K_2P_2O_7$		150 g/100 mL aq
hydrogen phthalate	$KHC_8H_4O_4$	204.22	1.636[25]	d		8.3 g/100 mL aq; sl s alc
hydrogen sulfate	$KHSO_4$	136.17	2.24	197	d to $K_2S_2O_7$	48 g/100 mL[20] aq
hydrogen sulfide	KHS	72.17	1.70	455–510		s aq, alc
hydrogen tartrate	$KHC_4H_4O_6$	188.18	1.956			0.5[20] aq; s acids; v sl s alc
hydroxide	KOH	56.11	2.044	406	1323	g/100 mL: 112[20] aq, 33 alc, 40 glyc
iodate	KIO_3	214.02	3.89[25]	560 d		8.1 g/100 mL[20] aq; i alc
iodide	KI	166.02	3.12	681	1345	g/100 mL: 144[20] aq, 4.5 alc, 50 glyc
manganate(VI)	K_2MnO_4	197.12		d 190	d 1400	s aq; stable in KOH
molybdate(VI)	K_2MoO_4	238.14	2.91[18]	919	d 400	160 g/100 mL aq
nitrate	KNO_3	101.10	2.109[16]	334.3		g/100 mL: 32[20] aq, 0.16 alc, s glyc
nitrite	KNO_2	85.10	1.915	441	d 350	306 g/100 mL[20] aq; sl s alc
oxalate hydrate	$K_2C_2O_4\cdot H_2O$	184.24	2.127[4]	anhyd 160	d to K_2CO_3	36 g/100 mL[20] aq
oxide	K_2O	94.20	2.32[20]	d 881[600mm]		d aq to KOH
oxobisoxalatodiaquatitanate(IV)	$K_2[TiO(C_2O_4)_2(H_2O)_2]$	354.18				v s aq
perchlorate	$KClO_4$	138.56	2.5298[25]	d 440		1.68[20] aq; i alc
periodate	KIO_4	230.01	3.618[15]	582		0.42[20] aq
permanganate	$KMnO_4$	158.03	2.703	d 240		6.34 g/100 mL[20] aq
peroxide	K_2O_2	110.20		490		d
peroxodicarbonate hydrate	$K_2C_2O_6\cdot H_2O$	216.24				6.5 g/100 mL aq; d hot aq
peroxodisulfate	$K_2S_2O_8$	270.32	2.477	d 100		2.5 g/100 mL[20] aq; i alc
perrhenate	$KReO_4$	289.30	4.38	555	1370	0.99[20] aq
phenolsulfonate hydrate	$KC_6H_4(OH)SO_3\cdot H_2O$	240.28	1.87			s aq, alc

TABLE 3.2 Physical Constants of Inorganic Compounds (*Continued*)

Name	Formula	Formula weight	Density	Melting point, °C	Boiling point, °C	Solubility (in 100 parts solvent)
Sodium						
hydrogen sulfide	$NaHS$	56.07	1.79	350		s aq, alc, eth
hydrogen sulfite	$NaHSO_3$	104.06	1.48	d		g/100 mL: 29 aq, 1.4 alc
hydroxide	$NaOH$	40.01	2.130^{20}_4	322	1557	g/100 mL: 108^{20} aq, 14 abs alc, 24 MeOH; s glyc
hydroxymethanesulfinate dihydrate	$Na[HOCH_2SO_2]\cdot 2H_2O$	154.12		63–64	d > 64	v s aq; i abs alc, bz, eth
hypochlorite 5-water	$NaClO\cdot 5H_2O$	164.52		18	d by CO_2	29 g/100 mL^0 aq
iodate	$NaIO_3$	197.90	4.227^{20}	d		8.1 g/100 mL^{20} aq
iodide	NaI	149.92	3.667^{25}	660	1304	g/100 mL: 200^{20} aq, 100 glyc, 50 alc; s acet
lactate	$NaOOCCHOHCH_3$	112.07		d		misc aq, alc
methoxide	$NaOCH_3$	54.03		>300		d aq; s alc
molybdate(VI) 2-water	$Na_2MoO_4\cdot 2H_2O$	241.95	3.28	anhyd 100; mp 687		65 g/100 mL^{20} aq
nitrate	$NaNO_3$	85.01	2.257	308		g/100 mL: 88^{20} aq, 0.8 alc
nitrite	$NaNO_2$	69.00	2.168^0	271	d ca. 500	67 g/100 mL^{20} aq
oxalate	$Na_2C_2O_4$	134.01	2.27		d > 320	3.4 g/100 mL^{20} aq; i alc
oxide	Na_2O	61.98	2.27	1132	d 1950	d aq to NaOH
pentacyanonitrosylferrate(III) 2-water (nitroprusside)	$Na_2[Fe(CN)_5NO]\cdot 2H_2O$	297.65	1.72			40 g/100 mL^{16} aq
perchlorate	$NaClO_4$	122.44	2.499	482		201 g/100 mL^{20} aq
periodate	$NaIO_4$	213.91	3.865^{16}	d 300		10.3 g/100 mL^{20} aq
peroxide	Na_2O_2	77.99	2.805	675		v s aq (dec)
peroxoborate 4-water	$NaBO_3\cdot 4H_2O$	153.88		d 60		2.5 g/100 mL aq
peroxodisulfate(VI)	$Na_2S_2O_8$	238.13		d	d	55 g/100 mL aq; d by alc
perrhenate	$NaReO_4$	273.19	5.24	300		33 g/100 mL^{20} aq
phosphate	Na_3PO_4	163.94		1340		12.1 g/100 mL^{20} aq
phosphate 12-water	$Na_3PO_4\cdot 12H_2O$	380.12	2.537^{18}	73.4	$-11H_2O$, 100	28.3 g/100 mL^{15} aq; i alc
phosphinate hydrate	$NaPH_2O_2\cdot H_2O$	105.99	1.62	anhyd 200	d to PH_3	100 g/100 mL^{20} aq; s glyc, alc; i eth